



# Conversion Process of a Ballistic Research Laboratory Computer-Aided Design (BRL-CAD) Model to a Panelized Surface Model (PSM)

by Robert W. Kunkel, Jr.,  
and John R. Anderson

ARL-TR-2396

February 2001

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## **Conversion Process of a Ballistic Research Laboratory Computer-Aided Design (BRL-CAD) Model to a Panelized Surface Model (PSM)**

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Survivability/Lethality Analysis Directorate

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## **Abstract**

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As the Department of Defense (DOD) develops new Survivability/Lethality and Vulnerability (SLV) analysis models, Ballistic Research Laboratory Computer-Aided Design (BRL-CAD) becomes an integral part in completing the task. BRL-CAD is very adaptable at creating new tools with little effort. These tools will assist us in continuing the development of Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS) by allowing the creation of a panelized surface model (PSM) with greater resolution. This PSM conversion methodology may also be utilized by others in the DOD community.

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## Executive Summary

Under contract, the Ballistics and Nuclear, Biological, and Chemical (NBC) Division of the Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD, had developed a model to analyze rotor-wash\* effects on chemical agent deposition for rotorcraft. This model, Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS), was developed by Continuum Dynamics, Inc., Princeton, NJ, under Contract No. DAAL01-95-C-0056. CADARS consists of two major elements: Lagrangian Deposition and Trajectory Analysis (LDTRAN) code and Vortex Trajectory Calculation (VTCALC) program.

The panelized surface model (PSM) is a key item that is utilized by CADARS. This report explains how the PSM is generated from a Ballistic Research Laboratory Computer-Aided Design (BRL-CAD) model and how it is used within CADARS.

A detailed description of the model is presented in the CADARS user's manual.<sup>1</sup> CADARS models a rotorcraft operating in a chemical agent cloud by predicting the airflow around the airframe and using particle trajectory algorithms to determine the chemical agent deposition on the airframe surface. Part of the input for CADARS is defined as a mission profile consisting of speed, height, direction, and time factors. The output from CADARS is defined as surface information at various locations on the panelized airframe. For each panel, airflow velocity vectors, local pressure gradients, and agent deposition rates are determined. The CADARS output is presented either in a tabulated numerical format or as a three-dimensional graphical output using color coding to identify individual panel data.

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\* Rotor-wash is the wind and vortices caused by the rotor blade moving through the air.

<sup>1</sup> Andrese, J. A., T. Q. Quackenbush, R. M. McKillip, T. B. Curbishley, and M. E. Teske. "Technical Description and User Notes for LDTRAN/CB Code Used in the Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS) Model." ARL-TR-1331, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, May 1997.

The first attempt at the conversion process used a special operations aircraft (SOA). The SOA program modified existing CH-47D Chinook cargo and UH-60A/L Blackhawk utility helicopters for multiservice special operations forces (SOF) missions. The MH-60K, which was derived from the UH-60A/L, was chosen for the conversion.

The RAH-66 Comanche target description was the second description that was converted to a PSM. The Comanche was first developed by Sikorsky Aircraft Company under contract with ARL (see Figure 1). It was created using BRL-CAD's Multidevice Graphics Editor (MGED).

The most recent attempt used the CH-47F Chinook, a next generation CH-47D. This model, along with data supplied by the chemical/biological agent vapor, liquid, and solid tracking (VLSTRACK)<sup>2</sup> was used to determine the chemical agent deposition on the aircraft.

As the Department of Defense (DOD) develops new Survivability/Lethality and Vulnerability (SLV) analysis models, BRL-CAD becomes an integral part in completing the task. BRL-CAD is very adaptable at creating new tools with little effort. These innovative tools will assist us in continuing the development of CADARS by allowing the creation of a PSM with greater resolution. This PSM conversion methodology may also be utilized by others in the DOD community. For example, a contractor at ITT Systems Corporation, AviDyne (formerly Kaman Sciences), has already benefited from this effort in performing blast loading on the Longbow Apache.

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<sup>2</sup> Bauer, T. J., and R. L. Gibbs. "Software User's Manual for the Chemical/Biological Agent Vapor, Liquid, and Solid Tracking (VLSTRACK) Computer Model, Version 1.6.3 (Windows)." NSWCDD/MP-97/196, Naval Surface Warfare Center, Dahlgren Division, Dahlgren, VA, September 1997.

# 1. Introduction

Under contract, the Ballistics and Nuclear, Biological, and Chemical (NBC) Division of the Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD, had developed a model to analyze rotor-wash\* effects on chemical agent deposition for rotorcraft. This model, Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS), was developed by Continuum Dynamics, Inc., Princeton, NJ, under Contract No. DAAL01-95-C-0056. CADARS consists of two major elements: Lagrangian Deposition and Trajectory Analysis (LDTRAN) code and Vortex Trajectory Calculation (VTCALC) program. More details about LDTRAN and VTCALC will be discussed in a later section.

**1.1 Purpose.** The purpose of this report is to document a process, utilizing newly developed Ballistic Research Laboratory-Computer Aided Design's (BRL-CAD) tools, that convert typical target descriptions into a panelized surface models (PSM). The converted descriptions can then be used as input to chemical agent deposition models used for survivability analyses.

**1.2 BRL-CAD Background.** The RAH-66 Comanche target description was first developed by Sikorsky Aircraft Company under contract with ARL (see Figure 1). It was created using BRL-CAD's Multidevice Graphics Editor (MGED) [1]. MGED is a program that provides the visual feedback and operator control necessary to build, modify, and validate highly complex geometric models of tanks, aircraft communication vans, etc. Since 1983, ARL has been constructing three-dimensional (3-D) solid models using BRL-CAD's MGED for subsequent use in vulnerability analyses. Approximately 120 target descriptions, both red and blue, have been created using BRL-CAD. The next few sections describe building blocks of BRL-CAD.

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\* Rotor-wash is the wind and vortices caused by the rotor blade moving through the air.

**1.2.1 Primitives.** The geometric solids most commonly used in creating a target description are derived from the following primitives: ARbitrary convex polyhedrons (ARB#) with four to eight vertices, ELLipsoids (ELL), TORii (TOR), and Truncated General Conics (TGC). These solids contain a specialized menu-driven parameter manipulation, which permits refined definition of a solid's shape and size. (See Ellis [2] for more details regarding these geometric solids.)

**1.2.2 Regions.** A geometric solid alone is insufficient in describing the complex shapes encountered in a target description. Combining solids using the three Boolean operators permits the imitation of the shape and form of the intricate objects. The Boolean operators are subtraction, intersection, and union. Boolean operations, which are binary, allow two solids or regions to be paired using the indicated Boolean operator. The result is processed as a new volume to be paired with the next solid and its specific Boolean operator. When Boolean operators are used to define a region, the region becomes a part of the database. A region can be as simple as a single solid or as complicated as hundreds of members combined with Boolean operators.

**1.2.3 Subtractions.** Subtracting two solids involves all the volume of the first solid less any common volume with the second solid. The subtraction operator (-) signifies subtraction and is useful in hollowing a body, removing an odd-shaped piece of solid, or accounting for edge intersection of walls, plates, piping, or other connected solids. One important restriction of the Boolean use that must be accommodated is the convention that regions must begin with a positive body. If an initial solid within a region is associated with the subtraction operator, the subtraction is ignored and the union operator is substituted.

**1.2.4 Intersection.** The intersection operation (+) combines two solids, saving only their common value. Unusual shapes can be attained using this operator; it is commonly used to save a piece of a shell, as in a radar dish, or to use only a portion of a standard primitive in a component's definition. Intersection between two solids having no common points would be the null set, which is a region having no evaluation potential.

**1.2.5 Union.** The concept of union is the converse of intersection. The union operator (u) joins solids so that any volume in at least one is part of the resulting volume. The union operation allows several related parts of a single component overlapping or trailing one after another to be defined in one region. Usefulness of the union operation is typified in creating wiring harnesses or fuel and hydraulic lines. For further details and insight into the target description process, see Ellis [2].

**1.3 CADARS Background.** The CADARS model was developed by Continuum Dynamics, Inc., Princeton, NJ, under contract with ARL. A detailed description of the model was presented in the CADARS user's manual [3]. CADARS models a rotorcraft operating in a chemical agent cloud by predicting the airflow around the airframe and using particle trajectory algorithms to determine the chemical agent deposition on the airframe surface. Part of the input for CADARS defines a mission profile consisting of speed, height, direction, and time factors. The output from CADARS is defined as surface information at various locations on the panelized airframe. For each panel, airflow velocity vectors, local pressure gradients, and agent deposition rates are determined. The CADARS output is presented either in a tabulated numerical format or as a 3-D graphical output using color coding to identify individual panel data (see Figure 2).

**1.4 VTCALC Background.** The first class of issues addressed in the development of CADARS involved basic features of the modeling of the rotor wake. The appropriate level of modeling for current purposes was assessed through extensive test calculations of predicted flow fields at key points near the rotor, with the goal of achieving a time-reduced computational burden. The best balance of accuracy and efficiency was achieved with a wake model consisting of two free vortex filaments trailing from each blade. The new wake model was embodied in a focused set of routines whose primary task was computing the geometry of the vortex wake of the rotor and its resultant velocity field. This software, designated the VTCALC Program, was used as a preprocessor for the LDTRAN.

**1.5 LDTRAN Background.** The coupled effect of the body, the body and its wake, and (when appropriate) the ground were computed on a volumetric grid of points and around the aircraft; a time-averaged flow field was then computed. (Time averaging was invoked since the flow field around a rotor was periodic with a period of 0.05 s; fluctuations on this time scale were short enough to be averaged for droplet transport.) The flow field was then used to convert an array of droplets from starting positions on the boundary of the computational grid until they either impacted on the fuselage surface or encountered another boundary of the grid. Using efficient interpolation and numerical integration schemes adapted from the FSCBG/AGDISP\* code, droplet trajectories were generated for each of the user-selected mission segments and chemical agents. The distances between the droplet trajectories and the panel centroids were then used in an interpolation scheme to compute the effective collection rate (mass/time) on each panel surface for each flight condition. Total accumulation on a panel was computed by scaling the collection rate by the total duration of exposure to a particular ambient concentration of the chemical agent in question. For further details regarding the two primary elements of CADARS, see Andrese [3].

## **2. Threat**

While this conversion method is being used in several chemical agent challenge analyses, it is independent of threat.

## **3. Scope**

CADARS uses a PSM, which is a 3-D computerized replication of the exterior airframe. The PSM is achieved by converting a BRL-CAD target description. The following sections will discuss the conversion process in detail.

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\* FSCBG/AGDISP = Forest Service Crame-Barry Grim and Agricultural Dispersal.

## 4. Theory for Supporting PSM Conversion

The first step in the conversion process is to modify the BRL-CAD target description to resemble the desired PSM. The most successful approach is modifying the BRL-CAD model to obtain the basic shape of the aircraft body with no openings to the interior and no holes through the body. CADARS does not calculate, at this time, any interior airflow, therefore all windows, doors, engine inlets, exhaust ducts, openings for the main rotor mast, and openings for the fan-in-fin must be closed. Exterior details such as antennae, landing gear and skids, and missile pylons should also be removed. Figure 3 depicts the Comanche in the mode just described. The interior components of the BRL-CAD model may be removed to improve processing time for the conversion, but is not necessary. Once the simplified BRL-CAD model is completed, a faceted shell representing the shape of the simplified model is created (see Figure 4). The two newly created BRL-CAD tools available for this part of the process are the `g-shell.radial` and the `g-shell.rect`. Both produce a single faceted shell in the form of an n-Manifold Geometry (NMG) solid by raytracing the simplified BRL-CAD model. These two newly developed tools are now part of the latest release of BRL-CAD.

The `g-shell.radial` program shoots rays from the perimeter of a series of circles with centers inside the BRL-CAD model. The points where each ray first intercepts the model are vertices of the PSM. The user provides a series of circle centers and a distance increment. The code interpolates between the specified centers and a distance increment. The code then linearly interpolates between the specified centers to produce a series of centers that are spaced at the specified distance increment. The user also specifies an angular increment of which to set the density of the rays fired around each circle. All the circles are oriented in the same direction (in parallel planes), user specified as the x, y, and z directions. This code is best applied to aircrafts with cylindrical-shaped bodies.

The `g-shell.rect` program begins by shooting rays in the y-direction on a uniformly spaced grid. Using this information, it then builds a crude shell. This shell is refined by using information obtained by shooting rays in the x and z directions. The user specifies the grid

spacing. The first shell created by this code will be two surfaces (consisting of the first and last ray intercepts) connected by straight lines in the y direction. The refining process adjusts the straight lines to more closely match the actual shape. This allows the process to consider recesses and subtle curvatures that the original raytracing in the y direction did not detect. The `g-shell.rect` code is generally more robust than the `g-shell.radial` but will require more computational time. (See Figure 5.)

The `g-shell.rect` and `g-shell.radial` should first be used to create the basic NMG shell. Any details added to the basic shell should be converted to NMGs separately using the same two tools. Details such as wings, pylons, horizontal stabilizers, and vertical stabilizers may be added in this manner. The question arises as to whether a part should be included with the main shell or added later as a detail. Some guidelines include the following:

- If the size of the part is about the size of the grid spacing or has a thickness on the x or z direction that is of the same order, then it should be converted to an NMG separately. Typically, the part may need to be rotated to get its largest presented area facing the y direction; then, the resulting NMG is rotated back to the original position.
- If important recesses cannot be seen from the cardinal views, then the parts that create those recesses must be converted separately.
- Any holes through the model should be filled and created later. Any remaining holes in the y direction will be represented by holes from the inside surface that are the boundaries of the grid cells and will not be improved by the refining rays. Any holes in the x or z direction will not appear.

After all the parts are converted to NMGs, they may be combined into a single BRL-CAD database file and made into a BRL-CAD region using the Boolean operations previously mentioned. The union operator should be used to join the different pieces, and the subtraction operator should be used to create necessary holes. The region may then be converted to a single



NMG solid using the g-nmg code. This code converts BRL-CAD regions to NMGs by performing the prescribed Boolean operations from the region, resulting in a single faceted NMG shell. This shell can be converted to the required PSM format using the nmg-sgp tool.

## **5. Implementation**

The first attempt at the conversion process used a special operations aircraft (SOA). The SOA Program modified existing CH-47D Chinook cargo and UH-60A/L Blackhawk utility helicopters for multiservice special operations forces (SOF) missions. The MH-60K, which was derived from the UH-60A/L, was chosen for the conversion (see BRL-CAD representations of the CH-47D Chinook and UH-60L Blackhawk helicopters in Figures 6 and 7, respectively). An MH-60K is shown in Figure 8.

## **6. Example**

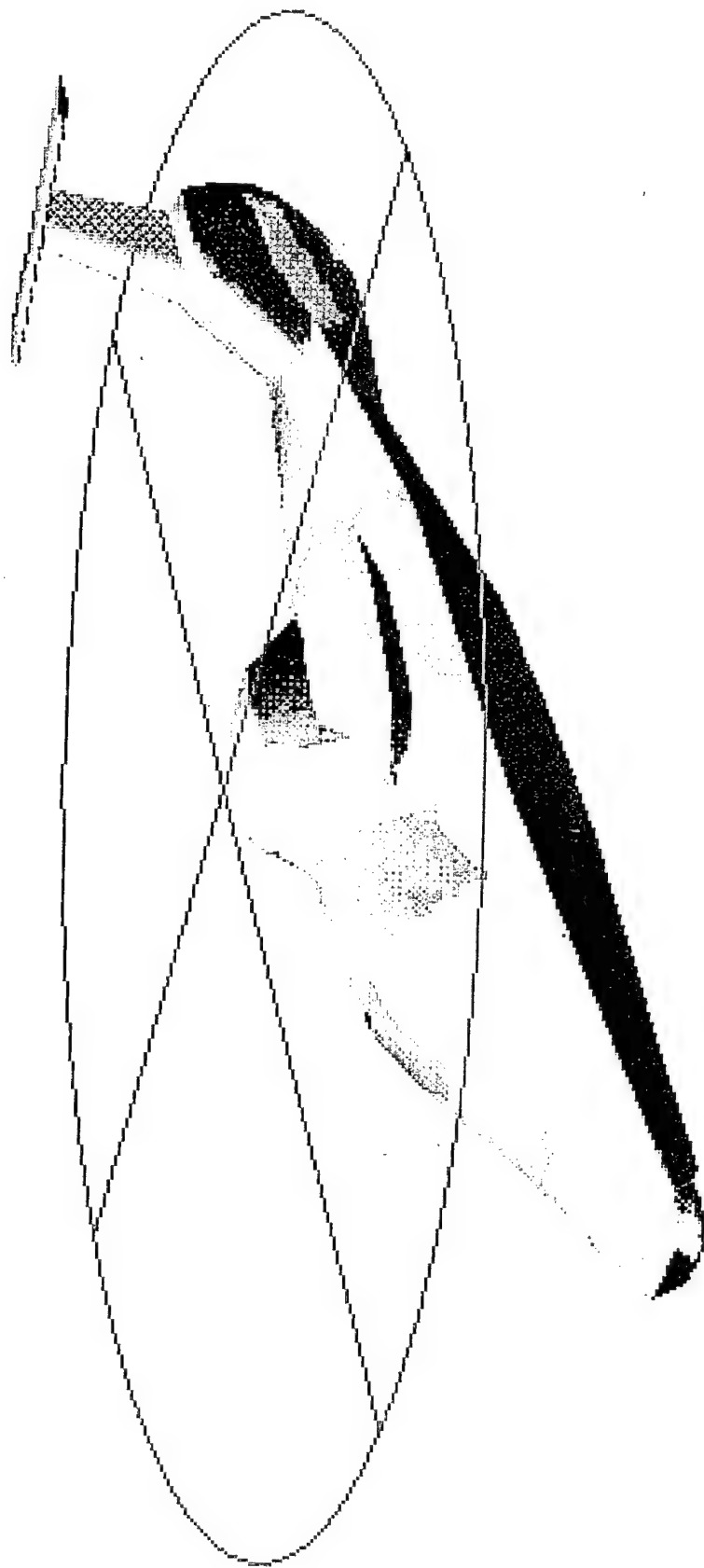
The most recent attempt used the CH-47F Chinook, a next generation CH-47D. Figure 5 portrays the BRL-CAD model of the Chinook, and Figure 9 depicts the converted CH-47F. This model, along with data supplied by VLSTRACK, was used to determine the chemical agent deposition on the aircraft.

## **7. Conclusion**

As new evaluation models are developed, conversion of the BRL-CAD model becomes an integral part in completing the task. BRL-CAD is very adaptable in creating new tools with little effort. These innovative tools will aid in the development of CADARS by allowing the creation of a PSM with greater resolution. This PSM conversion method can also be utilized by the DOD community. A contractor at ITT Systems Corporation, AvIDyne, has already benefited from this effort in performing blast loading on the Longbow Apache.



**Figure 1. The RAH-66 Comanche Helicopter.**



**Figure 2. Three-Dimensional Graphical Output Using Color Coding.**



**Figure 3. Simplified BRL-CAD Model.**

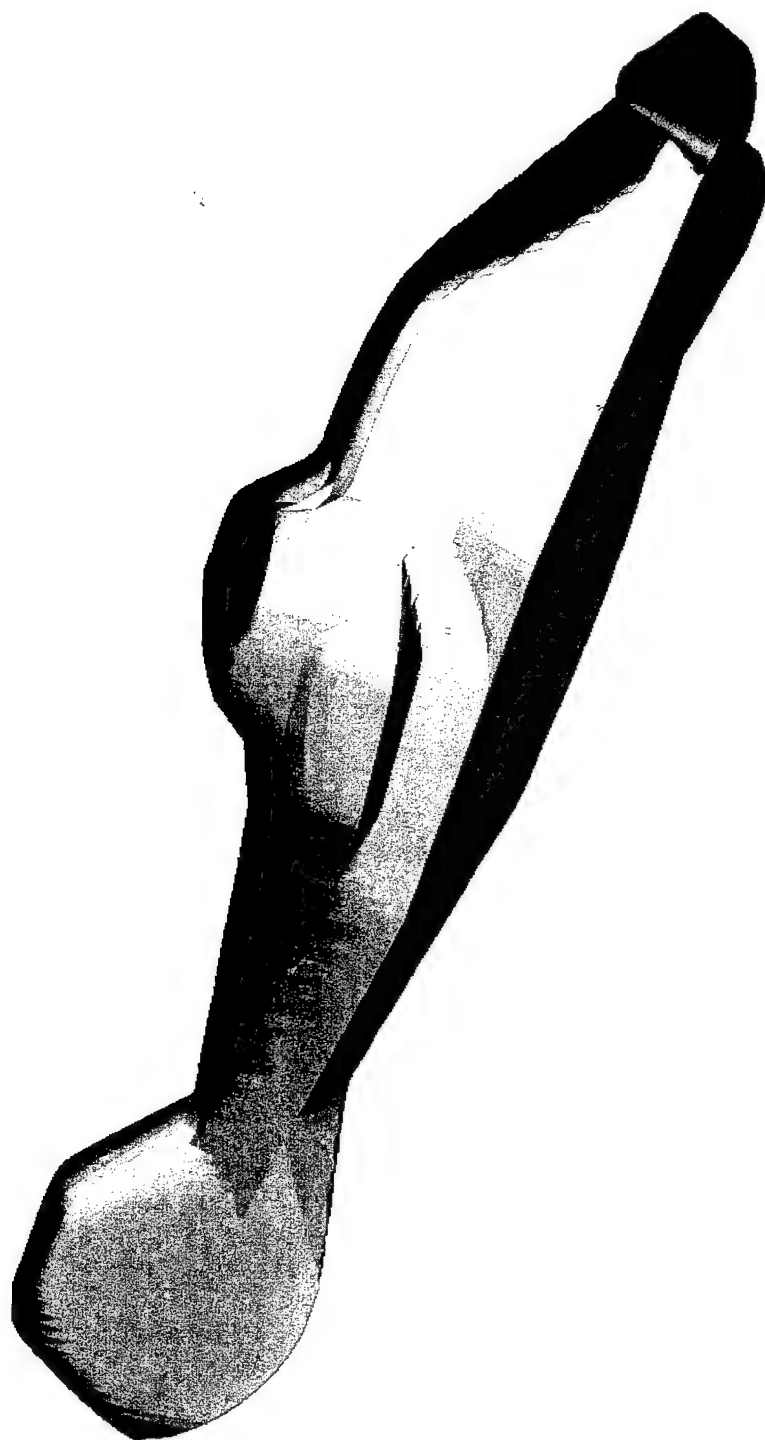
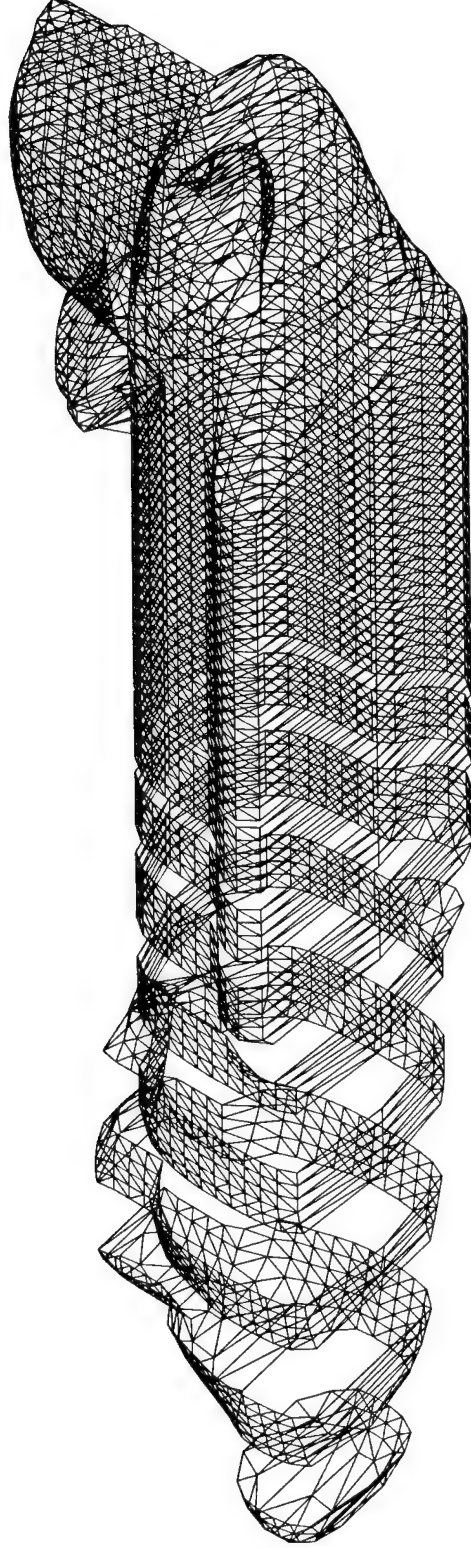
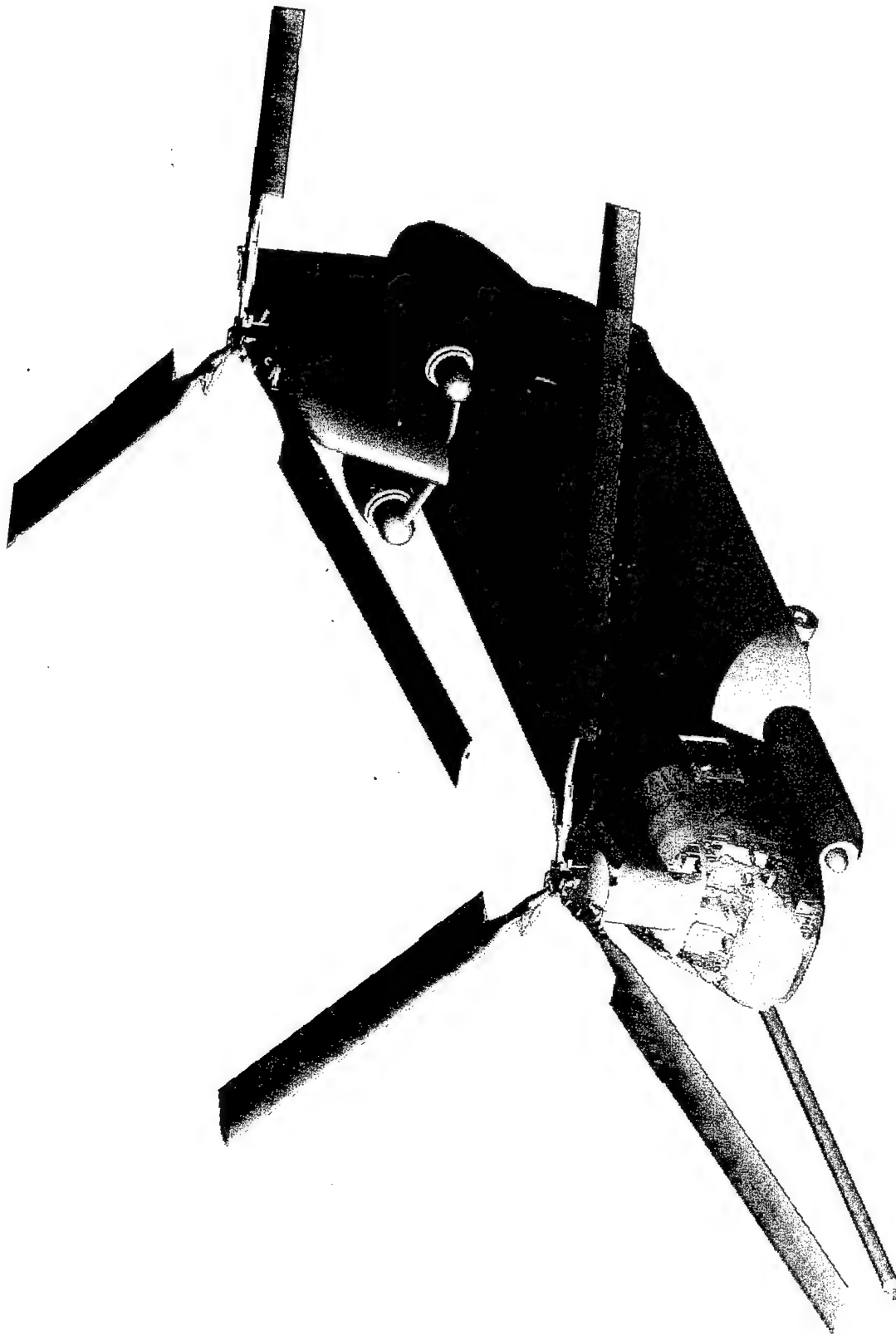


Figure 4. Facetted Shell Representing the Shape of the Simplified Model.



**Figure 5. “Exploded” View of CH-47F Shell Produced by the g-shell.rect Program.**



**Figure 6. The CH-47D Chinook Helicopter.**

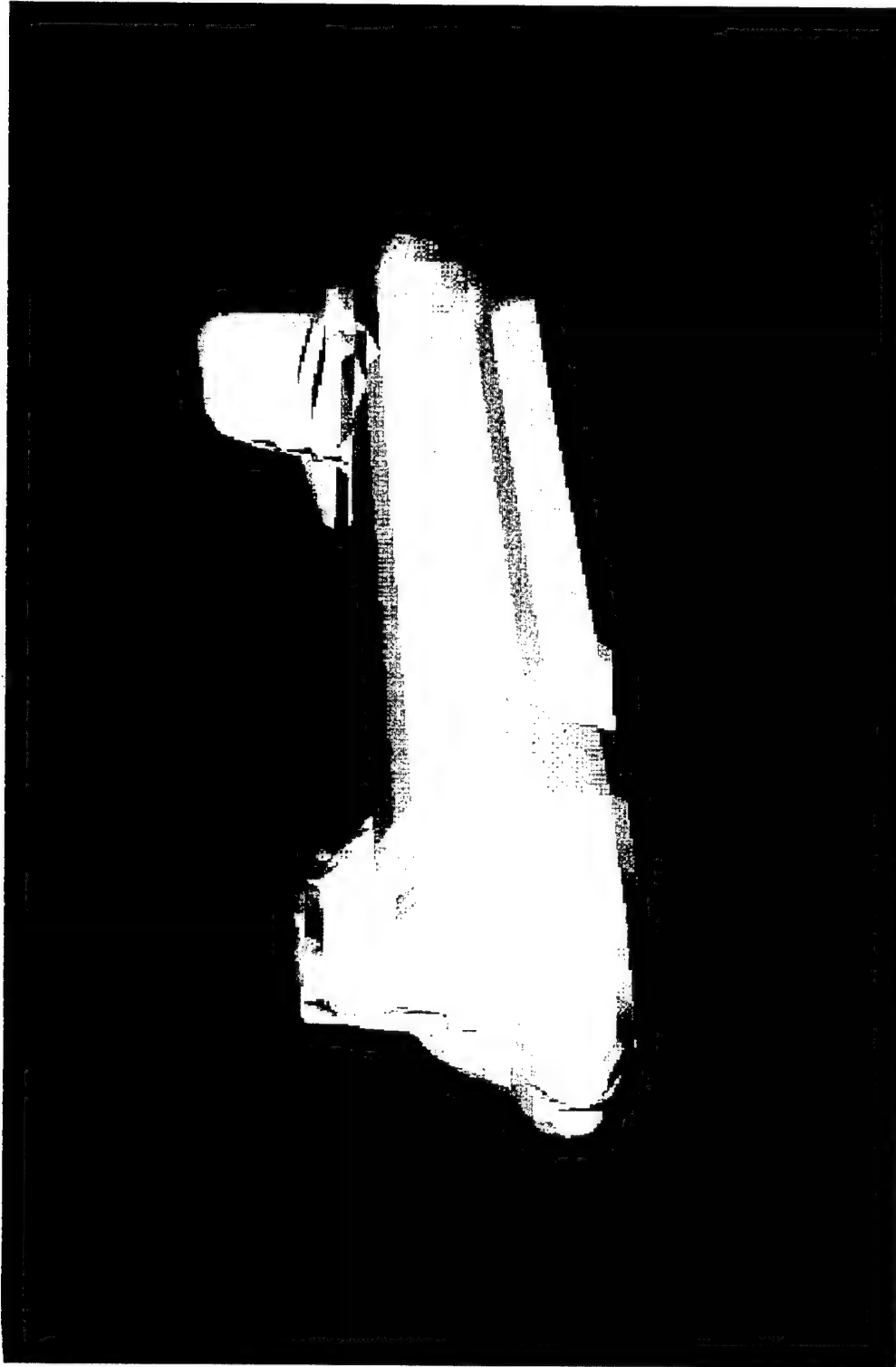


Figure 7. The UH-60L Blackhawk Helicopter.





**Figure 8. The MH-60K Helicopter.**



**Figure 9. The Converted CH-47F Chinook Helicopter.**

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4. TITLE AND SUBTITLE Conversion Process of a Ballistic Research Laboratory Computer-Aided Design (BRL-CAD) Model to a Panelized Surface Model (PSM)		5. FUNDING NUMBERS 665604D670		
6. AUTHOR(S) Robert W. Kunkel, Jr., and John R. Anderson				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRL-SL-BN Aberdeen Proving Ground, MD 21010-5423		8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-2396		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) As the Department of Defense (DOD) develops new Survivability/Lethality and Vulnerability (SLV) analysis models, Ballistic Research Laboratory Computer-Aided Design (BRL-CAD) becomes an integral part in completing the task. BRL-CAD is very adaptable at creating new tools with little effort. These tools will assist us in continuing the development of Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS) by allowing the creation of a panelized surface model (PSM) with greater resolution. This PSM conversion methodology may also be utilized by others in the DOD community.				
14. SUBJECT TERMS panelized surface model, CADARS, BRL-CAD, Army aircraft, rotorwash			15. NUMBER OF PAGES 29	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

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